

Fish Stocks in the Southern Scotia Arc Region— A Review and Prospects for Future Research

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*We provide a summary of biological aspects and population trends of demersal finfish stocks in the southern Scotia Arc region of Antarctica. Information presented here, drawn largely from recent scientific research surveys, includes aspects of species composition, biomass and stock structure, reproduction and early life history, age, growth, and natural mortality, and diet. Although Antarctic fish faunal groups overlap in the southern Scotia Arc, the region is dominated by species of low-Antarctic origin both in terms of biomass and number of species. Several basic biological parameters of the abundant fish species in the southern Scotia Arc are comparatively well known, though less so in the South Orkney Islands than the South Shetland Islands. These stocks suffered substantial declines as a result of commercial exploitation of mackerel ice fish, *Champscephalus gunnari*, and marbled notothenia, *Notothenia rossii*, in the late 1970s and mid 1980s. This led to a moratorium on directed fishing in 1989–90 which remains in effect. At present, several stocks, with the exception of these two species, appear to have recovered. A number of important biological features, such as age, growth, mortality, and the early life history of most species are still poorly understood. Key biological research needs are identified.*

Keywords Antarctic fish stocks, Scotia Arc

Introduction

The southern Scotia Arc is influenced by two hydrographic regimes: the Antarctic Circumpolar Current in the north and Weddell Sea water in the south. The islands of the Scotia Arc stretch from Shag Rocks close to the Southern Polar Frontal Zone (or Antarctic Convergence) in the north, in a wide eastward leading bow to the South Shetland Islands north and northeast of the tip of the Antarctic Peninsula (Figure 1). The southern part of the chain is formed by the South Orkney Islands (60–62° S/43–47° W), Elephant Island and its surrounding smaller islands Gibbs, Aspland, Eadie, and O'Brien, and the southern South Shetland Islands from King George Island in the east to Low Island in the west (60–62° S/54–62° W). The southern Scotia Arc forms the border between the Scotia Sea in the north and the Weddell Sea in the south (Shust, 1998). South Orkney Island and the South Shetland Islands are part of two Commission for the Conservation of Antarctic Marine

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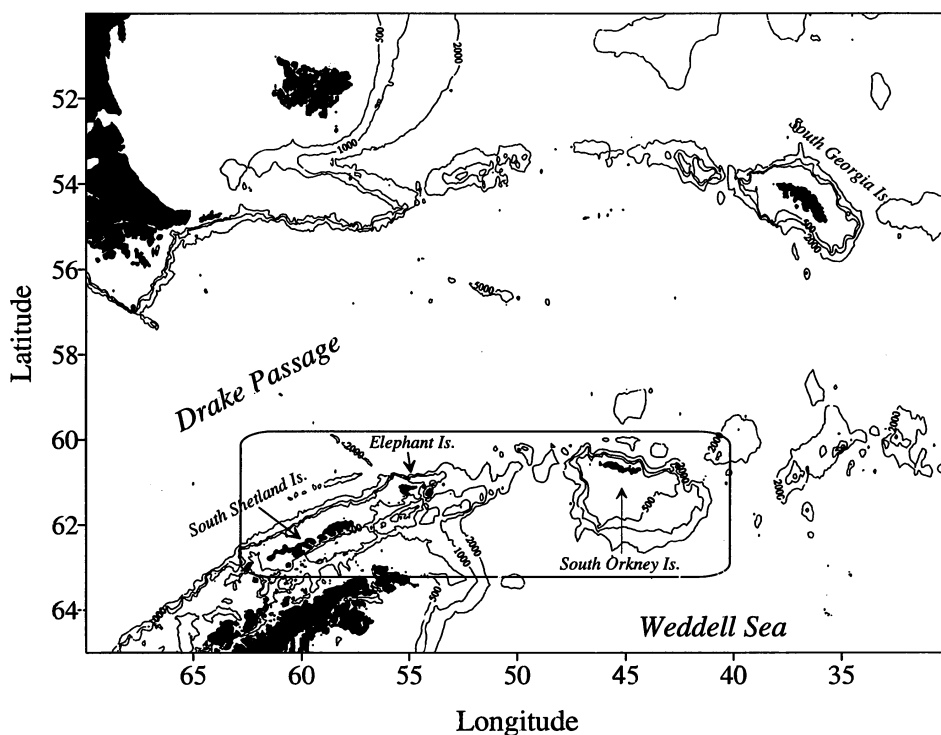


Figure 1. The southern Scotia Arc region of the Southern Ocean, roughly defined as the area within the box, including the South Orkney Islands, Elephant Island, and South Shetland Island groups.

Living Resources (CCAMLR) subareas: 48.1 (Antarctic Peninsula) and 48.2 (South Orkney Islands).

Research on fish species in the Scotia Arc started in the late 19th century (Fischer, 1885). Studies were confined to taxonomic studies for 80 years (Lönnberg, 1905, 1906; Regan, 1913; Norman, 1938; Nybelin, 1951). Biological work did not commence before 1965 when Soviet scientists started to collect fish during a number of research and exploratory fishing cruises (Kozlov and Pinskaya, 1971; Shust and Silyanova, 1971; Permitin, 1977; Permitin and Silyanova, 1971; Sherbich, 1975, 1976; Permitin and Tarverdiyeva, 1978; Shust and Pinskaya, 1978; Efremenko, 1979a, 1979b, 1983; Tarverdiyeva and Pinskaya, 1980; Tarverdiyeva, 1982; Kozlov and Tarverdiyeva, 1987; Kozlov et al., 1988). British scientists studied the distribution and early life history of some coastal fish species and the life cycle of *Notothenia coriiceps* (*N. neglecta* at that time) (Everson, 1968, 1969, 1970a, 1970b). Other countries, such as Poland, and East and West Germany, started their scientific work in the Southern Ocean in the mid-1970s (Gubsch, 1980, 1982; Kock, 1978, 1979, 1981; Freytag, 1980; Sosinski, 1981; Kock et al., 1985). However, until the 1980s, most research in the Atlantic Ocean sector still concentrated on South Georgia (Sherbich, 1976; Sherbich and Slepokurov, 1976; Shust and Pinskaya, 1978; Kozlov, 1980, 1981, 1982a, 1982b).

Commercial exploitation of finfish in the southern Scotia Arc region started in 1977–78 at the South Orkney Islands and spread to the South Shetland Islands in the subsequent season. The fishery has been managed by CCAMLR beginning in 1982 and the first

conservation measures were introduced in 1985. Despite substantial catches in the first 3–4 years of the fishery, little has been published by the fishing nations on the biology of exploited stocks (Permitin, 1969, 1973, 1977; Permitin and Tarverdiyeva, 1978; Tarverdiyeva and Pinskaya, 1980; Sosinski, 1981; Gubsch, 1982; Gubsch and Hoffmann, 1981). Most work has stemmed from a series of papers following research cruises by Germany in 1978, 1981, 1983, 1985–87, 1996, and 2002 (Kock, 1982, 1986, 1989a, 1989b, 1998a; Gröhsler, 1992, 1993; Tiedtke and Kock, 1989; Kock et al., 2002a, 2002b), Spain in 1987 and 1991 (Balguerías and Quintero, 1989; Balguerías, 1991) and the U.S. in 1998 and 1999 (Jones et al., 2000; Kock et al., 2000). Additional work, mostly on aging and other biological aspects, has been conducted on *Harpagifer antarcticus* and some nototheniids in the vicinity of Palmer Station (Anvers Islands, Antarctic Peninsula) at the very westernmost end of the Scotia Arc (Daniels, 1978, 1983; Radtke, 1987; Radtke et al., 1989a, 1989b; Radtke and Hourigan, 1990; Radtke and Kellermann, 1991; Ruzicka, 1996).

We have summarized existing knowledge on demersal fish stocks of the southern Scotia Arc to present a comprehensive picture of demersal fish stocks in the southern Scotia Arc and identify gaps in our knowledge. Information presented here has been primarily derived from recent scientific research surveys. Additional information is available from a large number of scientific papers by Russian, Polish, West and East German, British, American, Brazilian, Argentinean, and Chilean authors. Finally, we suggest directions for future research.

Material and Methods

The information contained in this article is largely drawn from recent scientific surveys conducted by Spain, Germany, and the United States. Sampling during all surveys described here followed a standard protocol, described in Balguerías (1991), Jones et al. (1998a, 2000, 2001), Kock (1989a, 1998a), and Kock et al. (2000, 2002a, 2002b). Sampling was based on a random depth stratified survey, but was restricted to areas where bottom conditions seemed to be moderate or good for trawling following initial acoustic bottom reconnaissance.

Most Antarctic fish species in the Scotia Arc are known to stay at or close to the sea floor during the day and ascend into the water column only at night, although *C. gunnari* may be an exception. When *C. gunnari* form dense aggregations, they often stay in the water column 20–30 m or even further above the bottom during the day (Frolkina et al., 1998; Frolkina, 2002). Sampling was therefore restricted to daylight hours for these surveys.

Gear types used were similar commercial-sized bottom trawls, though with some differences in gear configuration (Table 1). Comparison of the catch compositions of the German 140' BT and the American HBST at similar depths showed no more than 10–15% difference at most in catch composition. All trawls were thus assumed to have a similar catchability coefficient, assumed to be 100% for all species during all surveys (i.e., all fish in the path of the trawl were actually taken). Although likely to lead to an underestimate of stock biomass of some species (as it was unlikely that 100% of all species were captured), it was adopted as a conservative approach.

The three areas of the southern Scotia Arc studied were within the 500 m isobath of the Orkney Islands, Elephant Island, and the South Shetlands Islands. Biomass estimates used were from the South Orkney Islands in 1985, 1991, and 1999 (Kock, 1986; Balguerías, 1991; Jones et al., 2000), Elephant Island in 1978, 1981, and 1983 (only the 100–400 m depth range in both years), 1985, 1986, 1987, 1996, and 1998 (Kock, 1998a; Jones et al., 1998a) and from the South Shetland Islands in 1998, 2001 (Jones et al., 1998a), and 2002 (Kock et al., 2002a). All biomass estimates collected were recalculated to obtain an estimate based on the most recent calculations of seabed areas (Jones et al., 1999, 2000).

Table 1

Area, timing of the survey, research vessel, gear used, trawl dimensions (width, height), and number of hauls during bottom trawl surveys in the southern Scotia Arc, 1981 to 1999

Area	Time of survey	Vessel	Gear used	Trawl dimensions (width, height)	No. of hauls
S. Orkney Islands	Feb. 1985	Walther Herwig	140' BT	22.5 m, 2.5–3.0 m	30
S. Orkney Islands	Jan./Feb. 1991	Naroch	41.7/39.6 BT	26.0 m, 8.0 m	139
S. Orkney Islands	March 1999	Yuzhmorgeol.	HBST	18–20.0 m, 7–9.0 m	64
Elephant Island	March 1981	Walther Herwig	200' BT	23.5 m, 3.5–4.5 m	13
Elephant Island	Nov. 1983	Polarstern	140' BT	22.5 m, 2.5–3.0 m	13
Elephant Island	Feb. 1985	Walther Herwig	200' BT	23.5 m, 3.5–4.5 m	37
Elephant Island	May–June 1986	Polarstern	140' BT	22.5 m, 2.5–3.0 m	37
Elephant Island	Oct., Dec. 1987	Polarstern	140' BT	22.5 m, 2.5–3.0 m	40
Elephant Island	Nov. 1996	Polarstern	140' BT	22.5 m, 2.5–3.0 m	37
Elephant Island/S. Shetland Islands	March 1998	Yuzhmorgeol.	HBST	18–20.0 m, 7–9.0 m	72
Elephant Island/S. Shetland Islands	March 2001	Yuzhmorgeol.	HBST	18–20.0 m, 7–9.0 m	71
Elephant Island/S. Shetland Islands	January–February 2002	Polarstern	140' BT	18–19.0 m, 3–3.5 m	54

Species were identified according to Gon and Heemstra (1990) and modifications contained in Kock (1980, 1998b). Measurements of fish (total length to the next cm below), total weight, W_t , and gutted weight, W_g , were made according to Kock (1989a). To sample the length range of a given species as evenly as possible in order to establish comparable length-weight relationships between seasons or years, 5 individuals per cm-group and sex over the whole length range of a given species were collected. Sex and maturity stages were determined using the five-point scale of Everson (1977) and Kock and Kellermann (1991).

Gonad weights were taken from random samples. Ovaries for fecundity estimates were collected using a stratified sampling scheme to provide coverage of the whole length range of a given species. The following equations were used to describe the relationship between fish length/weight and fecundity:

$$F = a \cdot xL^b$$

and

$$F = a + b \cdot W_t$$

(Bagenal, 1973).

To estimate length at sexual maturity and length at first spawning, total length versus proportion of fish in maturity stages 2–5 and 3–5, respectively, for each sex were fitted to the logistic equation

$$p = \frac{1}{1 + e^{-(\alpha + \beta TL)}}$$

where p = estimated proportion of males and females in maturity stages 2–5 and 3–5, respectively (TL = total length and α , β = coefficients) (Ni and Sandeman, 1984). Definitions of other reproductive parameters, such as potential and relative fecundity, followed Kock (1989a).

Results

Species Composition and the Structure of Fish Assemblages

Species composition of the southern Scotia fish communities have been characterized since the late 1970s (Permitin, 1977; Kock, 1992; Kulesz, 1998). The overwhelming majority of species in terms of biomass (abundance) and numbers were of the suborder Notothenioidae, which included 77–92% of the species present and over 95% of individuals. Seven of the eight most abundant species were of low-Antarctic origin: *Gobionotothen gibberifrons*; *Champsocephalus gunnari*; *Chaenocephalus aceratus*; *Pseudochaenichthys georgianus*; *Lepidonotothen larseni*; *L. nudifrons*, and *Notothenia coriiceps*. The only high-Antarctic species in relatively high abundance was *C. rastrispinosus*, which made up 8.3% (Elephant Island) to 15.1% (South Orkney Islands) of all species caught by weight (Kock et al., 2000). Other high-Antarctic species, such as some *Trematomus* species and the channichthyid *Cryodraco antarcticus*, were also present in relatively high numbers, particularly around the South Orkney Islands (Table 2). Sampling between 500–800 m to the north of King George Island in December 1996 revealed that the proportion of high-Antarctic species, such as *Chionobathyscus dewitti*, *Neopagetopsis ionah*, or *Trematomus loennbergi*, as well as mesopelagic and deep-sea species (Hulley et al., 1998) increased below 500 m, whereas

Table 2

Proportion (in %, of fish numbers) of the biomass per subarea of the 10 most abundant fish species (N = number of hauls in the area). Only data collected until 1999 have been used

Species No. of hauls	South Orkney Islands N = 94	Elephant Island N = 219	South Shetland Islands N = 35
<i>G. gibberifrons</i>	45.69	53.96	24.67
<i>C. gunnari</i>	2.37	25.84	17.51
<i>C. aceratus</i>	6.10	7.26	4.74
<i>C. rastrispinosus</i>	7.69	0.54	3.76
<i>P. georgianus</i>	3.86	—	0.69
<i>C. antarcticus</i>	0.76	—	—
<i>L. larseni</i>	2.69	4.01	2.92
<i>L. nudifrons</i>	—	0.73	—
<i>L. squamifrons</i>	15.22	0.85	4.68
<i>N. rossii</i>	—	1.43	—
<i>N. coriiceps</i>	—	1.47	7.17
<i>Gymnoscop. nicholsi</i>	10.18	1.96	28.23
<i>Electrona antarctica</i>	2.74	—	2.17
	98.05	97.30	97.62

fish biomass made up primarily of low-Antarctic species declined substantially below 400–500 m (Kock and Stransky, 2000; Kock, 1980, unpublished data).

The suborder Notothenioidei includes five families; most species of the families Nototheniidae (15 out of 20 species), Channichthyidae (10 out of 15 species), and Harpagiferidae (one species only) were caught in the samples. Artedidraconidae (3 species only: *A. skottsbergi*, *Pogonophryne scotti*, *P. marmorata*) and Bathydraconidae (6 out of 16 species) were much less represented in our material. With a few exceptions, these two families appeared to be more high-Antarctic; the catch of even single individuals was uncommon in southern islands of the Scotia Arc.

All three island groups had similar ichthyofauna in terms of species, diversity, and biomass. The total number of species slightly increased from Elephant Island to the lower South Shetland Islands and the South Orkney Islands, with high-Antarctic species increasingly present in the south of the South Shetland and the South Orkney Islands (Kock et al., 2000). The abundance of species was 55–60% different between island groups (Kock et al., 2000). These differences were primarily caused by variation in the abundance of the most dominant species from one shelf area to the other (Kock et al., 2000) and little to do with the appearance/disappearance of certain species from one shelf area to the other. For example, *G. gibberifrons* was most abundant around Elephant Island and the South Orkney Islands but less dominant in the lower South Shetland Islands. *Lepidonotothen squamifrons* was abundant in the South Orkney Islands, pre- and post-spawning concentrations occurred on the northwestern part of the deeper shelf (>250 m) in March. They were much less abundant in other parts of the southern Scotia Arc.

The offshore demersal fish fauna on the shelf of Elephant Island included five groups of species that overlap to some degree in their depth distribution (Kock and Stransky, 2000). Differences between groups were primarily due to changes in the abundance of dominant low-Antarctic species between groups and the increasing occurrence of high-Antarctic

species below 200–300 m depth (Kock and Stransky, 2000). Fish assemblages in other areas of the southern Scotia Arc are likely to be similar.

The inshore fish fauna in two small inlets, Admiralty Bay and Potters Cove (King George Island, South Shetland Islands) consisted of about 12 species with *N. coriiceps* being most dominant. *N. rossii*, which had been the abundant species before the mid-1980s, subsequently declined substantially (Barrera-Oro and Marschoff, 1990; Zadrozny, 1996). Other abundant species included *L. nudifrons* and *T. newnesi*.

Biomass and Stock Identity

Biomass estimates prior to exploitation existed for one of the most abundant shallow water species, *N. coriiceps*, at the South Orkney Islands collected in the second half of the 1960s (Everson, 1970a) and for five abundant species (*G. gibberifrons*, *N. rossii*, *C. gunnari*, *C. aceratus*, *C. rastrospinosus*) in the southern Scotia Arc in 1975–76 and 1977–78 (Kock et al., 1985). Everson (1970a) studied the abundance of *N. coriiceps* in a limited area of Borge Bay (South Orkney Islands). However, these data were taken primarily in shallow water of <50 m, and were not comparable to more recent surveys (1985 onwards), which were all conducted more offshore in waters at usually 100 m and deeper (Kock, 1986; Balguerías, 1991; Jones et al., 2000; Kock et al., 2002a).

Biomass estimates for five abundant fish stocks in the southern Scotia Arc region before 1978–79 showed substantial stocks of *C. gunnari*, and to a much lesser extent, *N. rossii* (Kock et al., 1985). High catches of *C. gunnari* and *N. rossii* (only in 1979–80) were reported in the first 2–3 years after the fishery started in 1977–78. After the major commercial fishing operations were over in 1982 (Kock, 1991) biomass of fish stocks, particularly of the two target species *C. gunnari* and *N. rossii*, had declined dramatically to relative to their initial sizes (Tables 3 and 4). Neither species had recovered from exploitation since this period, although a very small increase in the biomass of *N. rossii* around Elephant Island was observed in the second half of the 1980s (Kock, 1989b).

By-catch species, such as *G. gibberifrons* and *C. aceratus*, were much less affected by the fisheries. Substantial increases in biomass estimates from 1985 to 1991 gave rise to the opinion that those fish stocks had largely recovered from exploitation. Stock sizes in 1996, 1998, and 1999 were similar to earlier estimates (Tables 3 and 4) which suggested the apparent rebuilding of these stocks. The South Shetland Islands (south of Elephant Island) were exploited primarily for *C. gunnari*, though catches of *N. coriiceps* were also reported by East Germany from north of King George Island (Kock, 1980, unpublished data). Recent scientific surveys suggest stock size of the by-catch species were comparable to those observed prior to exploitation (Table 5). However, the stock of *C. gunnari* remains at a low level.

Stock identity is poorly understood; information is only available on *C. gunnari* and to a much more limited extent on *N. rossii*. *C. gunnari* was found to form different stocks in the South Orkney Islands and the Elephant Island—South Shetland Islands (Kock, 1981; Sosinski, 1981; Sosinski and Janusz, 1986). Carvalho and Warren (1991) found only a small degree of genetic difference between fish in the South Orkney Islands and those further to the north at South Georgia. Although their findings supported some migration of fish between the two island shelves, no single individual of *C. gunnari* has yet been found outside shelf areas. Freytag (1980) found significant differences in some meristic characters of *N. rossii* between South Georgia and Elephant Island, and concluded that the two populations were distinct. Stock separation has not been attempted in other species. In the absence of data to the contrary, CCAMLR assumes that each shelf area is inhabited by a separate population.

Table 3
Biomass estimates (median, 95% CI) in tons of the nine most abundant fish species between 50–500 m around the South Orkney Islands (Jones et al., 2000). Data from 1976 and 1978 (Kock et al., 1985) are means only

Species	1976	1978	1985	1991	1999
<i>G. gibberifrons</i>	68,430	29,180	18,965 (10637–53,483)	53,483 (27,924–140,646)	38,900 (26,091–82,780)
<i>C. gunnari</i>	140,000	29,186	4824 (2297–18,318)	23,631 (12,274–61,450)	3016 (2027–6073)
<i>C. aceratus</i>	—	9854	5175 (2997–12,293)	16,031 (10,897–31,093)	10,431 (6628–22,220)
<i>C. rastrospinosus</i>	—	8759	4983 (2554–15,640)	15,410 (9353–30,368)	13,434 (7921–28,796)
<i>P. georgianus</i>	—	—	4739 (1319–42,432)	18,847 (9316–50,810)	8728 (4138–36,461)
<i>L. squamifrons</i>	—	—	6073 (1444–495,401)	14,156 (5429–56,617)	50,934 (15,129–373,309)
<i>L. larseni</i>	—	—	446 (239–1945)	455 (255–1049)	288 (205–718)
<i>N. coriiceps</i>	—	—	477 (159–9149)	—	264 (126–586)
<i>N. rossii</i>	133	284	163 (77–293)	412 (155–1719)	3278 (790–60,672)

Table 4
Biomass estimates (median, 95% CI) in tons of the eight most abundant fish species in the depth range 50–500 m around Elephant Island from 1981 to 2002 (Kock, 1998a; Jones et al., 1998a, 2001; Kock et al., 2002a).¹⁾ 1981 and 1983 100–400 m depth range only. Data from 1976 and 1978 (Kock et al., 1985) are means only

Species	1976	1978	1981	1983	1985	1986	1987	1996	1998	2001	2002
<i>G. gibberifrons</i>	16,471	17,824	10,948 (6173–23,754)	35,810 (9386–539,028)	12,069 (7517–29,458)	50,785 (31,112–605,274)	21,309 (10,982–45,679)	5157 (2679–212,193)	10,272 (4205–29,306)	4362 (2202–12,445)	3883 (1819–13,014)
<i>C. gunnari</i>	20,000	20,000	683 (195–8017)	1196 (505–3756)	502 (248–1561)	1040 (694–1909)	2059 (929–8406)	606 (374–1268)	2768 (1088–12,471)	2130 (962–7780)	957 (378–4229)
<i>C. aceratus</i>	—	1249	2879 (1181–15,122)	6499 (2952–30,939)	768 (532–1184)	7619 (4262–672,201)	5530 (3234–12,251)	2124 (1169–13,015)	965 (531–1887)	1458 (781–4201)	709 (420–1579)
<i>C. rastrosipinosus</i>	—	1015	83 (26–1092)	205 (69–1739)	243 (133–581)	284 (172–582)	475 (285–985)	282 (135–856)	551 (254–1887)	452 (310–742)	466 (238–1389)
<i>L. squamifrons</i>	—	—	542 (99–2415)	61 (6–15,034)	572 (168–5115)	313 (120–1489)	139 (48–809)	312 (65–5564)	998 (233–15,189)	334 (143–1372)	199 (65–1446)
<i>L. larseni</i>	—	—	170 (75–754)	138 (67–391)	94 (43–222)	170 (127–284)	533 (317–1115)	182 (131–269)	62 (35–143)	66 (35–160)	1547 (364–17,255)
<i>N. rossii</i>	9370	15,663	1834 (376–73529)	241 (106–938)	677 (161–27,135)	4524 (2149–19,457)	630 (223–3414)	32 (16–48)	78 (62–136)	98 (61–286)	316 (133–1933)
<i>D. mawsoni</i>	—	—	69 (23–162)	21 (6–209)	3 No conf. lim.	140 (68–254)	120 (61–259)	45 (24–336)	74 (18–1436)	82 (45–257)	144 (78–411)

Table 5

Biomass estimates (median, 95% CI) in tons of the nine most abundant fish species between 50–500 m depth around the South Shetland Islands in 1998 (Jones et al., 1998a, 2001), (Jones et al., 2001), and 2002 (Kock et al., 2002a). Data from 1976 and 1978 (Kock et al., 1985) are means only

Species	1976	1978	1998	2001	2002
<i>G. gibberifrons</i>	16,471	17,824	38,709 (17,882–119,902)	14,022 (7689–32,927)	13,889 (7304–36,229)
<i>C. gunnari</i>	20,000	20,000	8166 (4036–24,586)	5121 (3402–9587)	3019 (1509–16,787)
<i>C. aceratus</i>	—	1249	4440 (2782–615,956)	4581 (2856–8861)	2209 (1444–3987)
<i>C. rastrorpinosus</i>	—	1015	3011 (1785–6323)	4122 (2694–7375)	3420 (1864–8545)
<i>P. georgianus</i>	—	—	691 (424–1971)	928 (502–2407)	1330 (340–28,534)
<i>L. squamifrons</i>	—	—	3068 (1289–11,579)	1007 (491–2885)	1411 (411–11,808)
<i>L. larseni</i>	—	—	237 (157–406)	265 (170–473)	3595 (1170–19,983)
<i>N. rossii</i>	9370	15,663	344 (211–602)	873 (500–2089)	1793 (817–6861)
<i>N. coriiceps</i>	—	—	3232 (1719–9186)	7548 (3510–27,519)	4485 (1886–21,634)

Biological Parameters

Basic biological features of fish stocks in the southern Scotia Arc region was poorly understood until the mid to late 1980s (Naumov and Permitin, 1973; Permitin, 1969, 1973, 1977; Permitin and Silyanova, 1971; Permitin and Tarverdiyeva, 1978; Kock, 1981; Tarverdiyeva, 1982; Sosinski, 1985). Subsequently, in the wake of investigations conducted by Germany around Elephant Island since the early 1980s, Spain in 1986/87 and 1991, and the U.S. and Germany in the whole southern Scotia Arc since 1998 and activities by Argentina, Brazil, and Poland in inshore waters of King George Island, much more data have become available (e.g., Linkowski and Zukowski, 1980; Linkowski et al., 1983; Balguerías and Quintero, 1989; Balguerías, 1991; Barrera-Oro and Marschoff, 1990; Barrera-Oro and Casaux, 1992; Fanta et al., 1994; Kock, 1998; Kulesz and Zadrozny, 1996; Zadrozny, 1996; Jones et al., 1998a, 1998b, 2000; Kock et al., 2000, 2002a).

Reproduction and Early Life History

Data on length at sexual maturity (L_{50}) and first spawning (L_{m50}) exist for most of the abundant species (Table 6). However, there are still several gaps, particularly for *Lepidonotothen*

Table 6

Length at sexual maturity (L_{50}) and length at first spawning (L_{m50}) (in cm) of males (M) and females (F) of the most abundant nototheniids and channichthyids of the southern Scotia Arc

Species	Sex	South Orkney Island		Elephant Island		South Shetland Islands	
		L_{50}	L_{m50}	L_{50}	L_{m50}	L_{50}	L_{m50}
<i>G. gibberifrons</i>	M	30.0	33.0	30.1	36.4	30.7	33.7
	F	32.0	34.6	36.0	39.5	33.4	39.0
<i>L. larseni</i>	M	14.4	16.5		13.0		
	F	17.3	22.5				
<i>L. nudifrons</i>	M				12.4		
	F				13.0		
<i>L. squamifrons</i>	M	34.8				29.4	
	F	32.6	36.8			30.5	32.4
<i>N. coriiceps</i>	F				35.0		
<i>N. rossii</i>	M		42.5	42.2	45.2		
	F	47.6	51.9	49.9	52.6		
<i>T. eulepidotus</i>	M	22.4	22.4				
	F	27.5	27.8				
<i>C. gunnari</i>	M	33.8	35.3	32.0	46.2	32.1	35.6
	F	29.5	39.1	31.8	44.8	31.3	37.7
<i>C. aceratus</i>	M	36.1	44.0	39.5	44.6	38.2	46.9
	F	49.0	57.6	49.5	57.2	47.7	58.3
<i>P. georgianus</i>	M	38.1	45.1				
	F	38.4	45.6				
<i>C. rastrispinosus</i>	M	32.9	35.6	32.7	36.7	34.4	38.9
	F	34.0	36.7	31.2	33.2	34.4	36.4

larseni, *L. squamifrons*, *N. coriiceps*, *T. eulepidotus*, and *Pseudochaenichthys georgianus*. Existing information should be viewed with a number of caveats: first L_{50} , and particularly L_{m50} , were likely to be overestimated in some species, such as *L. larseni*, because gonad size of comparatively small-sized winter spawners was small in February–March, and maturity stages 1 (juvenile), stage 2 (adult, but resting), and beginning stage 3 (adult, gonads starting to mature) were difficult to distinguish from each other macroscopically. Second, in some other species, such as *C. gunnari*, the material was often dominated by single year-classes, and limited data was available for the critical maturation length range of 30–35 cm to allow reasonably precise estimates of L_{50} and L_{m50} .

Sufficient material was available to accurately estimate L_{50} and L_{m50} only in *G. gibberifrons*, *C. aceratus*, and *C. rastrispinosus* (Table 6) over the southern Scotia Arc, and for *L. squamifrons*, *N. rossii*, *T. eulepidotus*, *C. gunnari*, and *P. georgianus* in only parts of the region. Information on other species (Table 6) is still based on very limited data.

Sexual Dimorphism and Nest Guarding

Sexual dimorphism was observed in three species. In *C. gunnari* and *C. rastrispinosus*, sexually mature males had a significantly higher first dorsal fin than females (Olsen, 1955; De Witt and Hureau, 1979; Iwami and Abe, 1981). Adult *L. nudifrons* exhibited a distinct dichromatism between males and females: fins in juvenile males and adult females had brownish bars, whereas mature males had bright yellow unbarred fins (Hourigan and Radtke, 1989). *C. aceratus* and *T. bernacchii* had substantial differences in size between the two sexes. *C. aceratus* of 57 to 72 cm length were exclusively females (Kock, 1981). Maximum length in female *T. bernacchii* and *T. eulepidotus* was smaller than in females (Vacchi et al., 2000; Kock and Jones, unpublished data). Sexual dimorphism in size was likely to occur also in a number of other notothenioids for which age and growth have not yet been estimated.

Nest guarding has been observed in male *H. antarcticus* (Daniels, 1978), male *L. nudifrons* (Hourigan and Radtke, 1989). Indirect observations suggest that it was likely to occur also in *L. larseni* (Konecki and Targett, 1989) and female *T. bernacchii* (Moreno, 1980).

Gonad Cycle

The reproductive cycle is well known for *N. coriiceps* and *H. antarcticus* at Signy Island (South Orkney Islands) because of their proximity to a scientific station and possibility of year-round sampling (Everson, 1970b; White and Burren, 1992). For *G. gibberifrons*, *L. larseni*, *L. nudifrons*, *N. coriiceps*, *C. gunnari*, *C. aceratus*, and *C. rastrispinosus* at Elephant Island, gonado-somatic indices (GSIs) were collected from October to June, which enabled us to describe most of the annual cycle from our own data. Ovaries in resting stage weighed 2–4% while testes weighed 0.8–1.5% of the (total) body weight. Gonad maturation started 4–5 months prior to spawning. Close to or at spawning, ovaries reached 20–30% of the body weight for these seven species (Kock, 1989a) and 55–60% in *H. antarcticus* (White and Burren, 1992). Testes weight close to spawning differed considerably among species. The highest were in *G. gibberifrons*, *N. coriiceps*, and *N. rossii* with 15–25% and *H. antarcticus* with 10% of the body weight (Everson, 1970b; Permitin and Silyanova, 1971; Kock and Kellermann, 1991; White and Burren, 1992), but much lower (4–6%) in other nototheniids and channichthyids (Kock, 1989a; Kock and Kellermann, 1991).

Fecundity, Oocyte Size, and Spawning

Relative fecundity is known for most of the abundant species in the area, primarily low-Antarctic nototheniids and channichthyids (Table 7). However, fecundity of some, such as *L. squamifrons*, is unknown. Fecundity for most species has been determined for only one or two of the three subareas (Table 7). No information was yet available on inter-annual variation in fecundity.

Oocyte size close to or at spawning (Table 8) is known for the most abundant nototheniids and channichthyids and one harpagiferid, *H. antarcticus*. Oocyte size collected in combination with GSIs allowed estimation of the spawning season within a month (Table 8). With very few exceptions, such as *C. gunnari*, most species appear to spawn in all three subareas at about the same time, though often later than at South Georgia.

Spawning time is comparatively well known (Everson, 1970a, Kock, 1989a; Konecki and Targett, 1989; White and Burren, 1992; Kock et al., 2000). All abundant species are autumn-winter-early spring spawners. Only comparatively few species, such as *C. wilsoni*, *T. eulepidotus*, and *L. squamifrons*, spawn in spring-summer (Table 8).

Incubation of Larvae

Keys to the identification of fish larvae of Antarctic fish (Efremenko, 1983; Kellermann, 1990; North and Kellermann, 1990) allowed the identification of many species, particularly nototheniids and channichthyids, the mid-1980s, but information on arctodraconids and bathydraconids remained sparse. Data on the distribution and abundance of fish larvae were almost exclusively restricted to the Antarctic Peninsula/South Shetland Islands/Elephant Island region and South Georgia (Kellermann, 1990). Little information has been collected on larvae of the South Orkney Island fishes except on *N. coriiceps* (Everson, 1970b) and *H. antarcticus* (White and Burren, 1992) from Signy Island and a few larvae described in Everson (1968) and Efremenko (1983).

Direct observations of the development of Antarctic fish eggs were limited to three species. Eggs of *L. larseni* (diameter: 2.0 mm) were caught in early September and hatched soon after. They probably incubate for 2 months (Konecki and Targett, 1989). Eggs of *H. antarcticus* (diameter: 2.5 mm) kept in aquaria at Signy Island hatched after 3.5 months when being disturbed, and after 5 months when left undisturbed (White and Burren, 1992). Eggs of *N. coriiceps* (diameter: 4.3–4.8 mm) laid demersally in May–June along the Antarctic Peninsula, ascended to subsurface waters in their early developmental phase. After a long drift they hatched 5.5–6 months after spawning (Kellermann, 1991).

Hatching dates could only be extrapolated in other species from sizes of planktonic larvae. The most abundant (demersal) species in the ichthyoplankton in the Antarctic Peninsula/South Shetland Islands/Elephant Island region in late October–mid-November were *G. gibberifrons*, *L. larseni*, *L. nudifrons*, *T. newnesi*, *C. rastrispinosus*, and *C. antarcticus* (Skora, 1988; Kellermann, 1989), suggesting that they hatched in late September–October. In November–early December, *L. squamifrons*, *Pleuragramma antarcticum*, and *N. coriiceps* were abundant (Kellermann and Slosarczyk, 1984; Slosarczyk, 1986; White and North, 1987; Kellermann, 1989). *Trematomus scotti* did occur before January, and *C. hamatus* appeared at the beginning of the austral winter (Kellermann, 1989, 1996). Other species have been caught concomitantly (Kellermann, 1986, 1989) but in very low numbers. This makes it difficult to deduce their approximate hatching dates (Kellermann, 1989).

Very little is known about the distribution of fish larvae around the South Orkney Islands (Everson, 1968; Efremenko, 1983). Larvae of only a few species, such as *N. rossii*,

Table 7
Fecundity in the most abundant nototheniid and channichthyid species in the southern Scotia Arc region

Species	Locality	Length range (cm)	Potential fecundity	Relative fecundity	Fecundity in relation to	
					Length	Weight
<i>N. rossii</i>	Elephant Is	51–78	19,271–99,330	6.1–22.6	$F = 3.2459 \cdot L^{2.3114}$	$F = 9240 + 12.22 \cdot W$
<i>N. coriiceps</i>	S Orkney	36–47	7000–35,000	6.6–18.3		$F = 35.8 \cdot W^{1.1}$
<i>G. gibberifrons</i>	Elephant Is	34–55	6897–41,024	6.6–17.2	$F = 0.0103 \cdot L^{3.7969}$	$F = -2347 + 13.21 \cdot W$
	S Orkney	35–42	23,570–84,660	59–120		
	Elephant Is	34–47	21,699–143,620	36.8–100.0	$F = 0.93 \cdot 10^{-5} \cdot L^{6.0899}$	$F = -31624107.7 \cdot W$
<i>L. nudifrons</i>	S Orkney	12–22	792–6746	36–51	—	—
<i>L. larseni</i>	S Orkney	14–21	2337–7127	76–92		
<i>T. eulepidotus</i>	Elephant Is	15–21	1851–7070	56–105	$F = 0.728 \cdot L^{3.7734}$	$F = -124.3 + 80.4 \cdot W$
	Elephant Is	27–31	6043–12,854	22.2–32.1	—	—
<i>C. gunnari</i>	S Orkney	31–44	5169–9889		$F = 0.2574 \cdot L^{2.7744}$	$F = 1753 + 10.14 \cdot W$
<i>C. aceratus</i>	Elephant Is	34–50	3094–11,664	8.0–16.9	$F = 0.1216 \cdot L^{2.9177}$	$F = 1523.1 + 8.55 \cdot W$
	S Shetl. Is	32–47	3388–11,753	12.4–16.5	$F = 0.454 \cdot L^{3.2235}$	$F = 128 + 14.45 \cdot W$
	S Orkney	52–67	4499–15,174	3.9–6.8	$F = 0.0021 \cdot L^{3.7531}$	$F = 340 + 5.52 \cdot W$
<i>C. rastroripinosus</i>	Elephant Is	51–66	6711–19,672	4.9–9.2	$F = 0.0038 \cdot L^{3.6691}$	$F = 1073.7 + 6.0 \cdot W$
	S Shetl. Is	53–61	7375–12,450	4.6–8.2	$F = 0.0319 \cdot L^{3.0954}$	$F = 408.9 + 5.98 \cdot W$
	Elephant Is	33–47	1464–5136	3.6–6.4	$F = 0.2320 \cdot L^{2.5780}$	$F = 1089.2 + 3.21 \cdot W$
	S Orkney/ S. Shetl. Is	37.2–42.0	2510–4094	4–5		
<i>H. antarcticus</i>	S Orkney	—	559–993	76–99	—	—

Table 8

Egg size and spawning time in abundant notothenoids in the southern Scotia Arc region

Species	Egg size at spawning (mm)	Spawning time		
		S. Orkney Island	Elephant Island	S. Shetland Island
<i>G. gibberifrons</i>	1.8–2.0	August–September	August–September	—
<i>L. larseni</i>	2.0	July–August	June–July	June–July
<i>L. nudifrons</i>	2.5	—	April–May	—
<i>L. squamifrons</i>	1.4	February–March	February–March	—
<i>N. coriiceps</i>	4.3–4.8	May–June	May–June	May–June
<i>N. rossii</i>	4.7–5.0	May–June	May–June	May–June
<i>T. bernacchii</i>	>4.0	August–September	—	—
<i>T. eulepidotus</i>	2.8–3.0	March–April	March–April	—
<i>T. hansonii</i>	2.7–2.9	February–March	—	—
<i>T. newnesi</i>		(May) June–July	—	—
<i>C. gunnari</i>	3.5–3.8	July–August	(May) June–July	April–May (June)
<i>C. aceratus</i>	4.6–4.9	March–June (July)	April–June	April–June
<i>P. georgianus</i>	4.4–4.9	June–July	—	—
<i>C. rastrispinosus</i>	4.8–5.0	April–May	March–April	March–April
<i>H. antarcticus</i>	2.5	April–June	—	—

L. squamifrons, *Trematomus* spp., *P. antarcticum*, and *H. antarcticus* can be identified (Everson, 1968; Efremenko, 1983). The composition of the ichthyoplankton community in this region appears to some extent different from the Peninsula region (Loeb et al., 1993). However, observed differences from the other two subareas may only reflect poor sampling of this area compared to other regions (Loeb et al., 1993).

Larval growth rates of a number of species are known in the Antarctic Peninsula/South Shetland Islands/Elephant Island area, primarily from studies on the microstructure and chemical composition of otoliths at Palmer Station (Radtke et al., 1989a, 1993; Radtke and Kellermann, 1991). First comparative data suggest that growth of *G. gibberifrons* and *L. larseni* at the Antarctic Peninsula fell at the lower end of the South Georgia range (Ruzicka, 1996). Growth rates were 0.10 mm/day in *L. larseni*, but 0.19 mm/day in *C. rastrispinosus* and 0.20 mm/day in *P. antarcticum* (Keller, 1983; Hubold, 1985; Kellermann, 1986). Growth of *P. antarcticum* was similar to that estimated for the Weddell Sea (Keller, 1983; Hubold, 1985). Growth rates of larval *G. gibberifrons* less than 40 days old differed considerably between years.

Age, Growth, and Natural Mortality

Age and growth are the least known aspects of the life history of fish species in the southern Scotia Arc region, but are much better known at South Georgia (Sherbich, 1976; Shust and Pinskaya, 1978; Freytag, 1980; Gubsch, 1980; Kock, 1981; Frolkina and Dorovskikh, 1989; Kompowski, 1994; Kompowski and Rojas, 1996; Frolkina, 2000). However, validated age data are still very scarce.

Freytag (1980), using scales, concluded that *N. rossii* grow faster at South Georgia than at Elephant Island, but the observed differences may have been caused by methodological difficulties in the interpretation of annuli. Growth of juvenile *N. rossii* and *N. coriiceps* was

investigated in Admiralty Bay (Linkowski and Zukowski, 1980) and Potter Cove on King George Island in the South Shetland Islands. In the latter, offshore *N. rossii* were larger compared to fjord fishes (Barrera-Oro and Casaux, 1992), likely because larger fish migrate out of the fjords first. Age and growth, estimated from otoliths, were also studied in inshore *T. newnesi* in Admiralty Bay, in which L_{∞} and W_{∞} were close to maximum observed values (Kulesz and Zadrozny, 1996). Juvenile *N. rossii* and *G. gibberifrons* up to age class 7 dominate inshore catches in Admiralty Bay (Kulesz, 1996).

Tomo and Barrera-Oro (1985), using otoliths, found that female *C. gunnari* at Elephant Island with females grow 13 cm longer than male; however, age estimates were based on age classes 3–6 only. Modal length frequency peaks of juvenile *C. aceratus* increased by about 2 cm within 6-week periods between October and December 1987, probably from growth (Kock, 1989b). Larvae and juveniles of *G. gibberifrons* caught in early December 1987 formed three distinct size groups with modes at 8.4 mm, 4.9 cm, and 11.2 cm, probably age classes 0, 1, and 2, respectively. Daniels (1983), using additional data from Tomo and Cordero Funes (1972) found considerable differences in growth of *H. antarcticus* in the South Shetland Islands from neighboring areas west of the Antarctic Peninsula.

Growth profiles from the analysis of otolith microstructures (daily rings) have been established for *L. larseni*, *L. nudifrons*, *T. newnesi*, and *P. antarcticum* (Radtke and Targett, 1984; Radtke, 1987; Radtke et al., 1989b, 1993; Radtke and Hourigan, 1990; Ruzicka, 1992) and *H. antarcticus* (White (1991)). However, results were not verified by other independent methods of aging.

Mortality estimates of Antarctic fish are scarce. Everson (1970a) estimated the natural mortality of *N. coriiceps* at Borge Bay (Signy Island) in the mid-1960s at $Z = 0.36$, and Freytag (1980) calculated $Z = 0.29$ for *N. rossii* at Elephant Island between 1975 and 1978.

Length-Weight Relationships

A variety of length-weight relationships (LWRs), following the form

$$W = a \cdot L^b$$

exist for the most abundant species (Jones et al., 1998b; Kock, 1986; Kock et al., 1985, 2000), but are difficult to compare because the length-weight data were often unevenly spread over a species length range. Differences in sex and timing of sampling (see Kock et al. (1985) for comparison of LWRs) added additional variance. In this article, we selected only LWRs covering the greatest length range in a given species as evenly as possible (Table 9). The exponent b of the LWRs was lowest in the myctophids *Electrona antarctica* and *Gymnoscopelus nicholsi*. Among the notothenioids, *N. rossii* and *N. coriiceps* had the lowest b values. Length-weight relationships with high values of b ($3.9 \rightarrow >4.0$), such as in the case of *T. newnesi* and (to some extent) in *C. aceratus*, may have been biased by the high proportion of large fish and an under-representation of small individuals in the material. A more even distribution of the data over the whole length range (which, however, was not available for these species) would have likely led to values of b of 3.4–3.7 compared to the 3.9–>4.0 observed.

Food and Feeding

Qualitative food habits have been comparatively well studied in the South Shetland Islands-Elephant Island region (Tarverdiyeva and Pinskaya, 1980; Takahashi, 1983; Takahashi and

Table 9

Parameters of the allometric relationship of length and weight of fish species in the Scotia Arc region. Equations selected which cover the widest length range most evenly

Species	Area	a	b	N measured	Length range (cm)	R ²
<i>G. gibberifrons</i>	S. Orkney Is	0.0008	3.6500	510	9.8–51.2	0.99
	Elephant Is	0.0018	3.4911	657	12.5–44.5	0.99
	S. Shetland Is	0.0021	3.4354	160	22.5–40.5	0.96
<i>L. larseni</i>	S. Orkney Is	0.0042	3.2406	222	9.5–23.5	
<i>L. squamifrons</i>	S. Orkney Is	0.0033	3.3626	339	9.5–49.5	0.98
	Elephant Is	0.0023	3.4587	94	15.5–45.5	0.98
	S. Shetland Is	0.0023	3.4444	116	15.5–47.5	0.98
<i>N. coriiceps</i>	S. Orkney Is	0.0193	2.9865	32	33.5–48.5	0.91
	Elephant Is	0.0358	2.8196	57	33.5–54.5	0.92
	S. Shetland Is.	0.0075	3.2374	106	34.5–52.5	0.91
<i>N. rossii</i>	S. Orkney Is	0.0082	3.1604	157	37.5–66.5	0.94
	Elephant Is	0.0074	3.1944	713	31.5–68.5	0.97
<i>T. eulepidotus</i>	S. Orkney Is	0.0021	3.5829	146	15.5–34.5	0.95
<i>T. hansonii</i>	S. Orkney Is	0.0014	3.6315	51	16.5–45.5	0.98
<i>T. newnesi</i>	S. Orkney Is	0.0001	4.0490	24	14.5–24.5	0.96
<i>C. gunnari</i>	S. Orkney Is	0.0017	3.4211	530	12.5–51.5	0.96
	Elephant Is	0.0015	3.3821	594	11.5–46.5	0.99
	S. Shetland Is	0.0016	3.3400	185	11.5–44.8	0.99
<i>C. aceratus</i>	S. Orkney Is	0.0001	4.0484	516	14.5–70.5	0.97
	Elephant Is	0.0005	3.7054	206	17.5–70.5	0.99
	S. Shetland Is	0.0005	3.6722	202	14.5–71.5	0.99
<i>P. georgianus</i>	S. Orkney Is	0.0008	3.6500	122	16.0–52.6	0.99
	S. Shetland Is	0.0012	3.5685	64	18.5–55.5	0.99
<i>C. rastrosipinos.</i>	S. Orkney Is	0.0008	3.6822	321	16.5–48.5	0.96
	Elephant Is	0.0028	3.9483	167	29.5–46.5	0.92
	S. Shetland Is	0.0039	3.8557	346	25.5–45.5	0.92
<i>C. antarcticus</i>	S. Orkney Is	0.0006	3.5224	181	20.5–45.5	0.92
<i>E. antarctica</i>	S. Orkney Is.	0.2043	1.9618	199	6.5–10.5	0.66
<i>G. nicholsi</i>	S. Orkney Is	0.0472	2.4724	124	12.5–18.5	0.57

Iwami, 1997; Flores et al., 2004) and around Elephant Island (summer: J. Tiedtke, unpublished; late autumn–early winter: Gröhsler, 1992, 1993). In the South Orkney Islands, food composition is only known for the most abundant species (Permitin and Tarverdiyeva, 1978; Kock, 1981; Targett, 1981; Tarverdiyeva, 1982; Barrera-Oro and Tomo, 1987; Kozlov et al., 1988).

Feeding guilds presented here are divided into five groups: fish, fish and krill, krill, krill and benthos, and benthos (Table 10). All abundant fish species were krill feeders except for *G. gibberifrons* (benthos) and adult *C. aceratus* (fish). Nototheniids, and to some extent bathydraconids, fed on a variety of food species ranging from fish, such as in *Dissostichus mawsoni*, and krill, such as in *T. eulepidotus*, to benthic polychaetes and amphipods, such as in *G. gibberifrons* and *L. nudifrons*. The other three notothenioid families have broader

Table 10
Food preferences of fish species in the southern Scotia Arc regions

Food preference	Finfish species
Fish	<i>Parachaenichthys charcoti</i> , <i>C. aceratus</i> adults, <i>C. antarcticus</i> , <i>D. mawsoni</i> , <i>Chionobathyscus dewitti</i>
Fish and krill (<i>Euphausia superba</i>)	<i>N. rossii</i> , <i>N. coriiceps</i> , <i>T. newnesi</i> , <i>T. hansonii</i> , <i>P. georgianus</i> , <i>C. rastroripinosus</i> , <i>Gymnodraco acuticeps</i> , <i>Bathyrāja maccaini</i>
Krill	<i>T. eulepidotus</i> , <i>L. larseni</i> , <i>P. antarcticum</i> , <i>Aethotaxis mitopteryx</i> , <i>C. aceratus</i> juv.,* <i>L. squamifrons</i> ,* <i>C. wilsoni</i> , <i>C. gunnari</i> , <i>C. myersi</i> , <i>Neopagetopsis ionah</i> , <i>Pagetopsis macropterus</i> , <i>Micromesistius australis</i> , <i>Gymnoscopelus nicholsi</i>
Krill and benthos	<i>G. gibberifrons</i> , <i>Pogonophryne dolichobranchiata</i> , <i>Muraenolepis microps</i> , <i>Lycodicithys antarcticus</i>
Benthos	<i>L. nudifrons</i> , <i>T. bernacchii</i> , <i>T. scotti</i> , <i>Artedidraco skottsbergi</i> , <i>H. antarcticus</i> , <i>Paraliparis</i> sp., <i>Ophthalmolycus amberensis</i>

*Krill was replaced to a large extent by mysids (*C. aceratus*) or other pelagic organisms, such as scyphomedusae (*L. squamifrons*).

feeding habits: channichthyids eat fish and krill (mysids in juvenile *C. aceratus*), and artedidraconids and harpagiferids eat primarily amphipods and related prey groups (Permitin and Tarverdiyeva, 1978; Tarverdiya and Pinskaya, 1980; Targett, 1981; Wyanski and Targett, 1981; Gröhsler, 1992; Takahashi and Iwami, 1997).

Quantitative annual consumption rates are restricted to *N. coriiceps* and *C. gunnari* in the South Orkney Islands (Everson, 1970a; Tarverdiyeva, 1982), some nototheniids in the South Shetland Islands (Linkowski et al., 1983), and fish around the Elephant Island (Gröhsler, 1992, 1993). Mean daily food intake (estimated from stomach content weight) was 10.1% of the body weight (7.5–12.8%, primarily krill) in *C. gunnari* at the South Orkney Islands, modes varied from 0.5 to 2.5% in May and June 1986 and October and December 1987 (Gröhsler, 1992). Highest values were 5–6% in benthic feeders and 8–10% in krill eating species. These values are probably underestimates that need to be corrected for weight loss due to digestion.

Digestion time is the second most important variable that determines amount of food consumed daily, monthly, or annually. Digestion rates have been estimated either indirectly (Everson, 1970a; Tarverdiyeva, 1972, 1982; Gorelova and Gerasimchuk, 1981) or, to a lesser extent, directly from laboratory experiments (Naumov and Permitin, 1973; Crawford, 1978; Montgomery et al., 1989). Most estimates of digestion time, however, were obtained outside our study region. Digestion times varied between 28 and 120 h. Krill, for example, took 1.5–2.5 days to digest while fish took up to 4–5 days (Kock, 1985). Consumption rates estimated from stomach content weight and digestion time depends on the model used. Linear models gave results considerably different from nonlinear ones (Gröhsler, 1992).

Discussion

The History of Scotia Arc Fish Exploitation

Fish research in the (northern) Scotia Arc region started in 1882–83 when the German Transit of Venus Expedition overwintered on South Georgia and Fischer (1885) described the marbled notothenia, *N. rossii marmorata*. For the next 80 years, scientific studies on fish in the Scotia Arc region were taxonomic.

Various attempts to catch fish on a commercial scale were associated with whaling activities that commenced at South Georgia in December 1904 and soon spread to the South Shetland Islands and the Antarctic Peninsula. Fish had been sold to Buenos Aires (from 1905 onwards) before 1910 (Binnie, 1917; Walton, 1982; Dickinson, 1985). Attempts to fish on a larger scale before 1960 never went beyond the application stage (Dickinson, 1985; Kock, 1992), and the only fishing trials were by Olsen (1954, 1955), but did not lead to subsequent harvesting.

For almost 60 years, fishing was primarily a by-product of the much more lucrative whaling industry, but this changed when the Soviet Union began exploratory fishing of krill and fish in the Scotia Arc in the early 1960s (Kock, 1992; Shust, 1998). The first fishing trials in the South Orkney Islands were reported in 1965 when the Russian vessel “Akademik Knipovitch” surveyed the area for commercial fish concentrations (Kock, 1992). Large-scale exploitation of Antarctic fish stocks officially started with *N. rossii* at South Georgia in 1969–70, with some commercial fishing in the years prior to 1969, but the extent of this fishery remains unknown. In the southern Scotia Arc, fishing on a commercial scale started in 1977–78 when large concentrations of *C. gunnari* were detected on the southwestern shelf of Laurie Island (South Orkney Islands); almost 140,000 tons were taken within that one season, mostly by the Soviet Union. Poland and East Germany joined the fishery but on a much smaller scale (Kock, 1992).

The fishery spread to Elephant Island and the South Shetland Islands in the next year, when more concentrations of *C. gunnari* (possibly the same year-class as detected previously in the South Orkney Islands) were exploited. In 1979–80, the stock of *N. rossii* previously detected by German exploratory fishing in 1975–76 and 1977–78 off the north coast of Elephant Island (Kock, 1991) was reduced to only a small fraction of its initial size. Meanwhile, Polish and East German vessels caught 4,320 tons of spiny ice fish, *C. wilsoni*, north of Joinville Island off the tip of the Antarctic Peninsula. Catches declined substantially after this, when stocks of *C. gunnari* and *N. rossii* were exhausted.

Fishing thereafter occurred irregularly. Little more than a few thousand tons were caught annually (Kock, 1992), and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) closed the fishery after the 1989–90 season (Anonymous, 1989). The area was reopened for an unsuccessful exploratory longline fishery on *Dissostichus* spp. in waters deeper than 600 m in 1997–98 (Anonymous, 1998).

The course of the fishery was principally different at South Georgia from that in the southern Scotia Arc, where it followed three phases:

1. The trawl fishery on *N. rossii* at the end of the 1960s/beginning of the 1970s,
2. The trawl fishery on *C. gunnari* from the mid-1970s to the end of the 1980s, augmented to some extent by fisheries on *Patagonotothen guntheri* from the late 1970s to the late 1980s and the myctophid *Electrona carlsbergi* (1989/90–1991/92), and
3. The longline fishery on *D. eleginoides* since 1985–86.

In contrast, the fishery in the southern Scotia Arc was one single pulse from 1977–78 to 1980–81, and some less intense and more irregular fishing from 1981–82 to 1988–89. Large year-classes of *C. gunnari*, probably from the 1973 and possibly 1974 year classes, were observed in the second half of the 1970s. These yielded catches of 140,000 tons within one season at the South Orkneys in 1977–78 and 35,000 tons around Elephant Island and the South Shetland Islands in 1978–79. However, such large year-classes have never subsequently been observed (Kock, 1991). Much reduced parental stock sizes and possibly unfavorable environmental conditions or other ecological factors are among the most likely causes for small year-classes since then. Stocks of “by-catch” species had apparently recovered by the beginning of the 1990s and had fluctuated owing to annual changes in environmental conditions.

The Composition of the Fish Fauna in the Southern Scotia Arc

The composition and distribution of the fish fauna in terms of species and subareas was well known by the late 1970s (Andriashev, 1965; Permitin, 1977; Everson, 1984). South Georgia and Shag Rocks, the northernmost islands of the Scotia Arc, hosted the low-Antarctic (peri- or Lesser Antarctic) fish fauna only (Andriashev, 1965; Kock, 1992, Eastman, 1993). The number of fish species increased substantially south of the South Sandwich Islands, where a second faunal element, the high-Antarctic fauna, entered (Andriashev, 1965; Everson, 1984; Kock, 1992; Eastman, 1993). The highest numerical proportion of high-Antarctic species sympatric with low-Antarctic species was found in the South Orkney Islands (Kock et al., 2000), which was the area of the southern Scotia Arc most influenced by waters from the Weddell Sea. However, high-Antarctic species (with the exception of the channichthyid *C. rastrispinosus*) are a negligible proportion of fish biomass in the southern Scotia Arc.

Stratification of the fish fauna of an island shelf by fishing depth was found to be weak although apparent (Kock and Stransky, 2000). Five overlapping groups of species could be distinguished around Elephant Island. They differed by 55–60% between shelf areas, mostly due to differences in the abundance of low-Antarctic species between shelf areas and to the more frequent occurrence of high-Antarctic species below 200–300 m depth. This stratification is likely to be influenced by species-specific preferences for depth, bottom topography, and habitat, an area of research that has received little attention so far.

Composition of species groups changed considerably at depths below 500 m. Fishing trials north of King George Island at 500–800 m in December 1996 showed biomass of low-Antarctic fish declined sharply below 400–500 m and abundance of high-Antarctic fish, meso-pelagic, and deep-sea species increased considerably (Kock et al., 1998; Hulley et al., 1998). More investigations on the continental slope fish fauna are needed.

Biomass and Stock Identity

Biomass estimates of the abundant species collected at the beginning and in the course of fishing are needed for any responsible harvest of fish stocks. Estimates for the five most abundant species were available for the southern Scotia Arc from 1975–76 and 1977–78, i.e., prior to exploitation (Kock et al., 1985). Compared with estimates obtained in the 1980s and 1990s, the dramatic decline in the two target species, *C. gunnari* and *N. rossii*, from the few years of heavy fishing is clear. Catches of inshore juvenile *N. rossii* in Admiralty Bay (King George Island) declined dramatically after 1984, when almost all fish produced before the heavy fishing in 1979–80 had moved offshore (Barrera-Oro and Marschoff, 1990;

Kulesz and Zadrozny, 1996) to recruit to the adult stock. The then, much-reduced stock of adult *N. rossii* apparently produced a much lower number of juveniles, and after almost 20 years recovery has not occurred and stocks of both species are still fractions of their initial sizes.

Causes of failure to recover may differ in the two species. Most *C. gunnari* in the South Orkney Islands and to a lesser extent in the South Shetland Islands, were taken before first spawning, and did not contribute significantly to an increase in spawning stocks which remained low. The two *N. rossii* stocks followed a different pattern. The stock around the South Orkney Islands appears to have been small (not exceeding a few thousand tons) and was only fished in 1979–80 and 1983–84 (CCAMLR, 1990a). The larger stock around Elephant Island was detected during two exploratory fishing cruises by the German trawlers “Weser” and “Julius Fock” during commercial fishing trials in 1977–78 (Kock et al., 1985). Dense concentrations of *N. rossii* were confined to a limited area in the north of the shelf between 240 and 350 m depth. Catches of several hundred tons per season (= 20–35 tons per haul) were taken by the two German trawlers. This stock was fished extensively by a larger fleet from the Soviet Union in 1979–80; total catch was close to the size estimated for the total stock in 1977–78 (Kock et al., 1985), which was almost completely eliminated by the fishery. Catches taken in 1985–1987 consisted primarily of 5–8-year-old fish (Kock, 1986, 1989b) recruited to the stock afterwards. After 20 years, there has been no recovery. However, the status of *N. rossii* remains unclear. A survey to estimate stock size should include those areas in the north of the shelf that hosted most concentrations (and thus stock size) prior to exploitation.

“By-catch” species, such as *G. gibberifrons* or *C. aceratus*, were affected little by commercial harvesting, and these stocks declined to a much lesser degree. Surveys suggested that they recovered by the beginning of the 1990s and are now fluctuating in size according to changes in the strength of year-classes recruiting next (Jones et al., 2000; Kock, 1986, 1989b; Kock et al., 1998, 2002b).

A Spanish survey used a semi-pelagic trawl in 1986–87 (Balguerias and Quintero, 1989), although all other surveys in the region used bottom trawls. Because a semi-pelagic trawl has much less contact with the sea floor than a bottom trawl, Spanish biomass estimates strictly benthic species, such as *G. gibberifrons* and *C. aceratus*, were probably largely underestimated. Benthic-pelagic species, such as *C. gunnari*, which sometimes form large concentrations 5–20 m above the bottom even during daytime, may be more representatively sampled by benthic-pelagic trawls in these particular cases. However, in most cases, *C. gunnari* remains very close to the sea floor and is much better sampled by bottom trawls than semi-pelagic gear.

The southern Scotia Arc was closed for finfishing by CCAMLR after 1989–90 (CCAMLR, 1990b), and prospects for reopening commercial fishing in the near future appear remote because the only species that could withstand limited are *G. gibberifrons* and *L. squamifrons*. However, they could only be taken with a considerable by-catch of other species, such as *C. gunnari*, having much lower biomass, so that total allowable catches (TACs) for these species would be low, further limiting the prospects of exploitation.

Stock identity in *C. gunnari* is largely understood, whereas studies on other species are urgently required. Shelf areas in the Atlantic Ocean sector are usually inhabited by one population (Kock, 1981; Sosinski, 1981). It has been suggested that there are two different stocks around Shag Rocks and South Georgia (North, 1996), and the status of *C. gunnari* in the South Sandwich Islands and Bouvet Island needs clarification. Because the known depth range of most species rarely exceeds 600–700 m, CCAMLR assumes that deep oceanic waters separate each stock.

In the Indian Ocean sector of the Southern Ocean, more than one population of *C. gunnari* inhabits certain shelf areas. Two stocks (Kerguelen Islands, Skiff Bank) have been identified on the Kerguelen Plateau. The Heard and McDonald shelves host at least two populations of *C. gunnari* if not more (Williams et al., 1994; Duhamel et al., 1995).

Biological Aspects of Fish Stocks in the Southern Scotia Arc

Over the last 15 years, length at sexual maturity, length at first spawning, sexual dimorphism, gonad cycle, absolute and relative fecundity, spawning time, egg diameter, and incubation periods were studied for many of the abundant (predominately low-Antarctic) species in the southern Scotia Arc (Jones et al., 1998b; Kock, 1989a; Kock et al., 2000, 2002b). However, knowledge of basic biological parameters are still lacking for almost all high-Antarctic species occurring in the area. Until recently, little was known about the basic biology of species around the South Orkney Islands and the lower South Shetland Islands (Kock, 1986; Balguerías, 1991; Jones et al., 2000), and more information should be collected in forthcoming surveys.

The reproductive cycle is relatively well understood for the abundant low-Antarctic species, and is similar to the gonad cycle of *N. coriiceps* (Everson, 1970b). A long resting period of up to 6 or 7 months is followed by rapid ovarian growth. Ovaries reach 20–30% of body weight immediately prior to spawning. Spawning period may vary considerably between species, and spawning season appears to be comparatively short in *N. coriiceps*: more than 80% of the females around Elephant Island spawn between mid-May to mid-June (Kock and Kellermann, 1991). Variation in gonado-somatic indices of other species, such as *C. gunnari* and *C. aceratus*, suggests that their spawning season is 2–3 months (Kock and Kellermann, 1991).

Discrepancies exist on the ovarian cycle of the shallow-water *H. antarcticus* in terms of gonad weight close to or at spawning: gonad weights (in relation to body weight) provided by Daniels (1978) from Arthur Harbour (Antarctic Peninsula) and Tomo (1981) from Gerlache Strait were much lower than those of White and Burren (1992) for the South Orkney Islands. Methodological, and not stock-specific differences, likely accounted for the observed large discrepancies.

Whether all sexually mature fish of a population spawn every year remains unknown. At South Georgia, 15–25% of the population of *C. gunnari* do not spawn annually (Lisovenko and Silyanova, 1980; Sosinski, 1981). When krill is scarce around South Georgia and the condition index of fish is lower than normal (Kock, 1989d; Everson and Kock, 1999), up to 50–60% of the fish may not spawn. Other populations of *C. gunnari* (Sosinski, 1981; Kock, 1989a) act similarly. In contrast to the populations in the Atlantic Ocean sector, *C. gunnari* around Kerguelen Islands attains sexual maturity between 24–26 cm, and the whole mature population spawns annually thereafter (Sosinski, 1981; Duhamel, 1987).

Oocyte shrinkage needs to be taken into account when oocyte diameters are compared. Estimates of oocyte (egg) diameter have often been of preserved ova without stating the preservative. Measurements of fresh oocytes 1998 and 1999 suggest that oocytes reserved in 4% buffered formaldehyde shrink by 5–10%; in various kinds of alcohol shrinkage of oocytes is considerably greater.

Early life history studies started only 20 years ago. The first comprehensive keys to early life history stages became available in the 1980s (Efremenko, 1983; Kellermann, 1990; North and Kellermann, 1990), and subsequent comprehensive reviews of Antarctic larval fish (Kellermann, 1990; Loeb et al., 1993) allow many fish larvae to be identified. However, these investigations were mostly restricted to South Georgia (Efremenko, 1983;

North, 1990) and the Antarctic Peninsula-South Shetland Islands region (Kellermann, 1986, 1989, 1990). Species succession occurs from early spring to late summer–early autumn and changed considerably in composition from year to year (Kellermann, 1986, 1989; Loeb et al., 1993). To date, little more than distributional patterns of larvae and post-larvae and growth have been studied.

Studies on larval abundance inshore have been confined to a limited area around Signy Island (Everson, 1968; White and Burren, 1992) and the South Shetland Islands facing Bransfield Strait, Bransfield Strait itself, and Gerlache Strait (Tomo and Cordero Funes, 1972; Daniels, 1978, 1983; Sinque et al., 1986, 1990; Laman and Loeb, 1995). One focus of these studies was on *H. antarcticus*, whereas studies on other species were sparse. Larval distribution and abundance in the South Orkney Islands region remained poorly understood. Extreme seasonal and interannual variability was apparent in the composition and abundance of Antarctic larval fish assemblages in offshore waters of the South Shetland Islands (Loeb et al., 1993). The observed differences may reflect to a large extent interannual variation in adult condition factors, reproductive effort, survival of eggs and larvae, and variable environmental conditions (Loeb et al., 1993). Most species descend to the bottom towards the end of their first year, but some species such as *L. larseni*, *L. squamifrons*, and *T. scotti*, have overwintering larvae that became demersal juveniles during their second summer (Kellermann and Schadwinkel, 1991). Future early life history work in the southern Scotia Arc should focus on the distribution and abundance of fish larvae in coastal waters of the Antarctic Peninsula-South Shetland Islands, in shelf waters around the South Orkney Islands, and in off-shore shelf areas, to obtain more information on the interannual variability of larval fish communities. Otolith microstructure should be studied to obtain information on early growth of Antarctic fish.

Length-weight relationships (LWR) are available for all abundant fish species (Table 9) in the area (Kock, 1986; Kock et al., 1985, 2000). Interannual variation in LWRs is unknown because of rather nonsystematic sampling before 1998.

The only two studies on aging for fishes in the southern Scotia Arc before 1981 were on *N. coriiceps* at Signy Island (Everson, 1970a) and *N. rossii* around Elephant Island (Freytag, 1980). Both studies showed that the two species grew up to 16–20 years. Attempts to determine age of Antarctic fish were made by Scientific Committee on Antarctic Research (SCAR) in 1979 (Anonymous, 1980, 1982; Everson, 1980, 1981) and continued by CCAMLR in the late 1980s (Anonymous, 1988). CCAMLR also established an exchange system for comparative readings of otoliths and scales between different laboratories in 1986 (Kock, 1989c). Most of these samples were from peri-Antarctic species either from South Georgia or the South Shetland Islands. Only one was from the high-Antarctic (*P. antarcticum* caught in the Mawson Sea close to the Antarctic continent). Results demonstrated Everson's (1980) and Freytag's (1980) notion that larger-sized low-Antarctic nototheniids, such as *N. rossii* and *G. gibberifrons*, and high-Antarctic species, such as *P. antarcticum* grew up to 18–20 years. Results from these age readings, however, revealed that substantial differences in the interpretation of age determinations between readers existed, particularly in the interpretation of ages of older fish (Kock, 1989c). Despite these differences in the interpretation of ages, results of the exchange scheme were promising, but comparative age readings between labs have only been taken up in 2001 on *Dissostichus spp.* (Anonymous, 2001b) and *C. gunnari* in 2002 (Anonymous, 2001a).

Another way of estimating age was the use of daily increments in Antarctic fish otoliths. Age determination of small-sized species, such as *L. larseni* (Radtko and Targett, 1984), or *T. newnesi* (Radtko et al., 1989b) was verified using this method. However, a comparison of results using otolith microstructures and conventional aging methods in *N. rossii* and

C. gunnari from South Georgia revealed considerable differences in ages of fish older than 5 or 6 years (Radtke, 1990). Ages from microstructures were consistently higher than from conventional methods, suggesting that otolith microstructures in older fish were not deposited on a daily basis as in post-larvae and early juveniles but have an unknown periodicity. Age estimates and their reliability should be another major topic for future research on fish stocks in the southern Scotia Arc.

Mortality estimates in fish from the southern Scotia Arc were limited to two species, *N. coriiceps* at Signy Island (known as *N. neglecta* at the time of the study) and *N. rossii* at Elephant Islands. Mortality estimates of $Z = 0.36$ and $Z = 0.29$ for *N. coriiceps* and *N. rossii* appear high given that both species may reach 18–20 years old (Everson, 1970a; Freytag, 1980). Older fish may have been underrepresented in the samples from inshore shallow waters (*N. coriiceps*) or in bottom trawl catches (*N. rossii*). Mortality of *C. gunnari* at South Georgia was initially estimated at $M = 0.25$ to 0.35 . However, *C. gunnari* was found to have a comparatively short lifespan at South Georgia in that most specimens disappear when they become older than 5–6 years. Therefore, M was corrected to $M = 0.48$ – 0.55 (Frolkina and Dorovskikh, 1989; SC-CAMLR, 1991). In the southern Scotia Arc, *C. gunnari* probably has a lower natural mortality than further north, since sexual maturity is obtained at a greater length (30–35 cm) and fish of age classes 7–10 are still observed in larger numbers in the stocks. Studies on *C. gunnari* are particularly interesting because of the differences in life history observed between stocks on more northerly grounds, such as South Georgia or Kerguelen-Heard Plateau, and the southern Scotia Arc.

The feeding habits of many offshore fish species of the Antarctic Peninsula-South Shetland Islands-Elephant Island region are well known (Tarverdiyeva and Pinskaya, 1980; Takahashi, 1983; Tiedtke, 1989; Gröhsler, 1992, 1993; Takahashi and Iwami, 1997), but this is not the case inshore (Moreno and Osorio, 1977; Moreno and Zamorano, 1980). Prey composition is even less known in the South Orkney Islands (Permitin and Tarverdiyeva, 1978; Targett, 1981; Wyanski and Targett, 1981; Tarverdiyeva, 1982; Barrera-Oro and Tomo, 1987) than in the other two subareas. With the exception of Gröhsler (1992, 1993), who analyzed data collected in May–June 1986 and October and December 1987 from the whole shelf of Elephant Island, and Targett et al. (1987), who presented preliminary information from samples taken along the Antarctic Peninsula in August–September, all sampling has been confined to summer.

Differences in food consumption between subareas are minor, i.e., fish eat the same food in the South Orkney Islands and the southern South Shetland Islands. Differences in prey composition between subareas or even between various fishing grounds within a subarea were often caused by the short-term availability of prey, such as krill, to benthic feeders, and by the short period over which investigations were conducted (commonly only a few days). It is unknown how quantitatively important this phenomenon is and to what extent benthic-feeding fish feed regularly on krill and other zooplankton in the water column, rather than on or near the bottom. *C. gunnari* ascend to 50 or 100 m in the water column at night to prey on krill (Frolkina, 1993, 2000, 2002; Frolkina et al., 1998).

The first crude extrapolation of krill consumption by the seven most abundant fish species gave estimates varying considerably between years and to the extent by which a fish stock was already affected by commercial fishing. For example, annual food consumption by *N. rossii* off Elephant Island in the mid to late 1970s declined dramatically after the stock was heavily depleted in 1979–80 (Kock, 1992), but annual consumption by “by-catch” species, such as *C. aceratus*, remained fairly stable (Kock, 1985). More refined estimates for the Elephant Island area in 1986–87 demonstrated that not more than 11,000 tons of krill were consumed by the abundant fish species after stocks of the krill-eating *C. gunnari*

and *N. rossii* were substantially reduced by fishing. About 6,000 tons of this were eaten by the benthos-feeding *G. gibberifrons* alone (Gröhsler, 1992). Krill consumption around Elephant Island has probably declined since 1986–87 because of the reduction in stock size of *G. gibberifrons* (due to natural causes) and continuous low stock size in the krill feeders *C. gunnari* and probably *N. rossii* (Kock, 1998a). The first extensive information on quantitative food intake and local variation in feeding in late autumn–early winter was provided for fish around Elephant Island (Gröhsler, 1992, 1993), who observed no difference in the extent of feeding between summer and early winter. However, further studies on food composition, food intake, and daily food consumption in winter are urgently required.

Other crucial parameters for the estimation of food consumption are digestion time and daily estimates of food intake. Mean daily intakes were generally 0.5–2.5% in all species investigated (Kock, 1992), but could reach 5–10% in *N. rossii*, *C. gunnari*, or *D. eleginoides* in periods of intensive feeding (Tarverdiyeva, 1972, 1982). Results from all field studies fell well within limits provided by other authors for Antarctic fish (Everson, 1970a; Crawford, 1978; Kompowski, 1980; Targett, 1981; Chekunova and Naumov, 1982a, 1982b; Burchett, 1983; Linkowski et al., 1983; Shust, 1987). Experimental (Crawford, 1978, Chekunova and Naumov, 1982a, 1982b) and field data estimating food intake (Targett, 1981; Tarverdiyeva, 1982; Gröhsler, 1992; Takahashi and Iwami, 1997) has given conflicting results. Observations from nototheniids suggests that food intake decreases in winter (Chekunova and Naumov, 1982a, 1982b; Linkowski et al., 1983), but other investigations found feeding rates were similar in summer and winter (Everson, 1970a; Crawford, 1978; Targett, 1981; Gröhsler, 1992). Studies of *N. coriiceps* and *L. larseni*, results from different researchers gave similar results (Everson, 1970a; Crawford, 1978; Targett, 1981; Linkowski et al., 1983). These studies show that results from a few days of sampling, as is often the case, should be regarded with caution when extrapolating to a whole season or when attempting interseasonal comparisons.

Knowledge of fish stocks in the southern Scotia Arc increased substantially after a number of scientific surveys were conducted. Future surveys are likely to fill in gaps in the knowledge identified here. These surveys need to be augmented by work at field stations on aspects such as digestion time or daily food intake, which is difficult to study at sea. Sampling and studies should be extended to the autumn–winter time to obtain more data from this season.

Results from recent research cruises to the southern Scotia Arc showed that there is little potential to reopen a commercial fishery in the near future. Catches taken by bottom and pelagic trawls may take several by-catch species in relatively substantial numbers, whereas by-catch species with a low stock size may have a higher risk of depletion. Research on fish stocks in the southern Scotia Arc should be intensified, in particular around the South Orkney Islands, the least known of the three island groups. Species of primary interest are those that have been exploited in the past, such as *N. rossii*, *G. gibberifrons*, *C. gunnari*, *C. aceratus*, *P. georgianus*, and *C. rastrispinosus*, and those that are ecologically important due to their ubiquity, such as *N. coriiceps* in waters down to 200 m and *L. squamifrons* in waters below 250 m. The collection of high-Antarctic species at the northern margin of their distributional range may serve as a comparison with individuals collected in the Weddell Sea and the Ross Sea.

Major topics of future research cruises to the region could be:

- Structure of demersal fish communities and assemblages in the South Orkney and the South Shetland Islands
- Biomass estimates of the abundant demersal fish species

- Data on reproduction and its interannual variability in selected fish species
- Early life history of coastal demersal species, fish species in the South Orkney Islands, and the interannual variability in the early life history of the offshore fish fauna
- Age and growth of demersal fish species
- Food composition of demersal fish species in winter
- Food consumption of different demersal fish communities in summer and winter
- Seabed characteristics and habitat preferences of abundant demersal fish species.

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